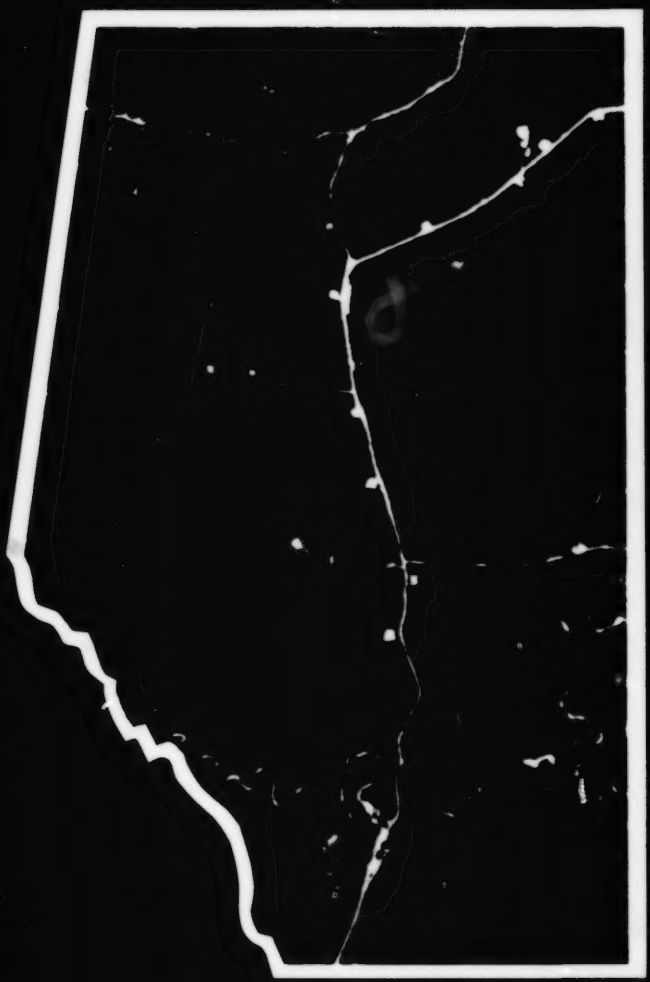
REMOTE SENSING

of Seismic Lines



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REMOTE SENSING OF SEISMIC LINES

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DEMONSTRATION PROJECT

This is the abridged edition of a remote sensing demonstration project report (Strong, 1986) sponsored by the Alberta Remote Sensing Center, Alberta Environment. The complete report is available for in-Center study.

COVER PHOTOGRAPH

A summer (4 August 1984) Band 7 Thematic Mapper scene from an area south of Grande Prairie, Alberta; which contains linear disturbance features such as major haul and secondary access roads, and seismic lines.

ABSTRACT

The visual analysis of 38 Landsat images from four study areas suggests that Thematic Mapper (TM) imagery is more suitable than Multispectral Scanner (MSS) imagery for detecting linear disturbance features such as seismic lines which are associated with oil and gas development in forested regions. Although TM imagery was the more effective product, its efficiency was <40% relative to 1:60,000 aerial photography. Summer TM color composite Bands 2,3, and 4 (TM 234) and black and white band 5 (TM 5) images were found to be most efficient on an overall basis for detecting disturbance features, although summer TM 7 detected a somewhat greater proportion of narrow disturbances (<10m wide). In contrast, winter MSS imagery was found to be more effective than summer MSS imagery. The detection efficiency of most TM imagery was >75% for features >10m in width, but <30% for seismic lines and trails (<10m wide). Sixty to 100% more km of linear disturbance were detected on TM imagery than MSS.

Discriminant Analyses of vegetation and site data from 200 distubances indicated that the width of a disturbance and the presence of unvegetated ground were of primary importance in promoting their detectability. Disturbances which transect coniferous or mixed deciduous/coniferous stands tend to be more easily detected than in pure deciduous stands, since most regrowth on disturbances is dominated by deciduous and herbaceous plants. Threshold values for detection were usually smaller for TM imagery than MSS (e.g. 7m wide vs 22m, respectively). Orientation of the lines and height of vegetation on the disturbance did not significantly influence their detection. Vegetation height may be an important factor but further field work will be required to properly evaluate this variable.

Thematic Mapper imagery may be a useful tool for monitoring recent oil and gas activities with its greatest potential in areas where coniferous vegetation is abundant.

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INTRODUCTION

The development of Landsat-4, and the subsequent launching of Landsat-5, has resulted in imagery with greater detail than was available from earlier satellites equipped with only Multispectral Scanner (MSS) instrumentation. This increased detail is attributed to improved spatial resolution; an increase from 80m to 30m (Anonymous, 1982). Since its introduction in 1984, this higher resolution product, termed "Thematic Mapper (TM) imagery", has been the subject of comparative analyses to determine its potential capabilities and limitations. Published studies to date have largely involved the comparative analyses of areal landscape features such as vegetation, topography, agricultural, or urban patterns (e.g. Tilton and Conner, 1985; Ackleson et al., 1985). However, the potential use of Thematic Mapper imagery for detecting linear features has received only modest attention (e.g. Snowsill, 1985; Colwell and Poulton, 1985).

The ability to detect linear features such as seismic lines (narrow linear features created with bulldozers during geophysical exploration, often arranged in grids with a spacing of 1-2km), secondary roads, and other related disturbance features on a periodic basis could be a valuable tool for natural resource managers, especially in forested areas where their location and abundance has many implications. Such management implications include changes in the response patterns of wildlife to local conditions (Horejsi, 1979), the destruction of habitat, increased vulnerability of wildlife to hunting, and the erosion of the forest land base. In 1981, Hardy Associates (1978) Ltd. estimated that approximately 303,300ha of Alberta's forested land had been disturbed by petroleum construction and related activities. Of this total, seismic lines composed 70% with additional 10% in the form of oil and gas roads and well sites. Although the total amount of disturbance was only 1% of the total area, this percentage will continue to increase with time due to continued exploration and slow regrowth by the native vegetation.

Until recently, narrow linear disturbances were difficult to detect through satellite remote sensing. The regular updating of maps of rapidly developing areas was often frustrated if these lines were undetectable by satellites and where aerial photographic missions were prohibitively expensive. Other methods of inventorying disturbance features, such as ground surveys, are not only costly but labor intensive. Thus, the use of high resolution satellite imagery could provide an inexpensive tool for detecting seismic lines and secondary roads. Potential users of this information include those wishing to monitor resource development, natural resource managers, and persons involved in the mapping of such features (e.g. provincial access and forest cover maps).

This publication summarizes the results of a study, sponsored by the Alberta Remote Sensing Center, which assessed the capability of selected Landsat images for detecting linear disturbances such as seismic lines. In addition, the methods used for this assessment are provided, so other image bands from different landscapes can be tested and directly compared.

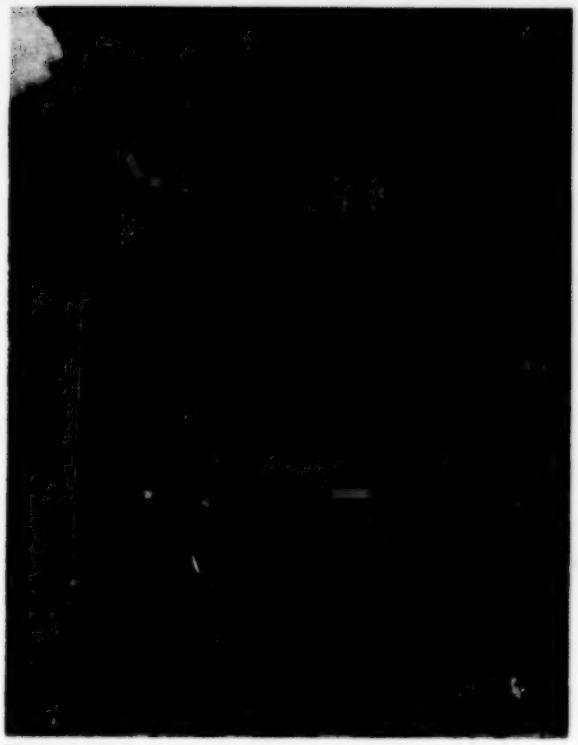
STUDY AREAS

Four Alberta 1:50,000 NTS map sheets located in areas of known oil and gas activity (Figure 1) were selected for study: Big Mountain Creek (83L 14), Wapiti (83L 15), Nordegg River (83B 13), and Loon River 84B 12). Each map was approximately 890km^2 in size.

The Big Mountain Creek, Wapiti, and Nordegg River areas occur on the eastern limits of the Rocky Mountain foothills. Topographically, these areas consist of benchlands which are arranged in a series of steps that increase in elevation from an east to west direction in the Nordegg River area (Dutchak, 1980), and northeast southwest direction in the Grande Prarie area (Twardy and Corns, 1980). Local relief does not exceed 75m/km, except where breaks occur between benchlands. The Loon River map area occurs within the Northern Alberta Lowlands (Pettapiece, 1985). The eastern two-thirds of the landscape consists primarily of an undulating lacustrine plain with numerous poorly drained depressions. In contrast, the northwestern portion of the area is dominated by hummocky moraine deposits which flank the lower slopes of the Buffalo Head Hills. Local relief between knolls and depressions did not exceed 10m, although slopes of 30% did occur.

The majority of land encompassed by the Big Mountain Creek, Wapiti, and Nordegg River map sheets was located within the Boreal Foothills Ecoregion of Alberta, while the Loon River area occurred in the central portion of the Boreal Mixedwood Ecoregion (Strong and Leggat, 1981). Forest vegetation dominated the landscape of the Boreal Foothills Ecoregion with mixed stands of aspen, balsam poplar, paper birch, lodgepole pine, and white spruce. Common plant names follow those used by Moss (1983). Deciduous dominated stands were common at lower elevations, while pure lodgepole pine stands occurred at higher elevations.

Figure 1. Location of Study Areas (A - Loon River, B - Wapiti, C - Big Mountain Creek, and D - Nordegg River).



Photograph 1

An example of a typical forest located on a moderately well-drained site in the Boreal Foothills Ecoregion. Lodgepole pine commonly occur with aspen and balsam poplar. Photograph taken near Rocky Mountain House.

Photograph 2

A typical upland Boreal Mixedwood stand, which is primarily composed of aspen with secondary quantities of balsam poplar. White spruce can become increasingly important as stands age. This stand was photographed northwest of Red Earth Creek.

Photograph 3

Black spruce stands with low-growing evergreen shrubs and mosses typify poorly-drained depressions in both the Boreal Mixedwood and Foothills Ecoregions. This particular stand is in the Athabasca area of Central Alberta.

Photograph 1 represents a typical forest stand that could be found on moderately well drained sites in the Boreal Foothills Ecoregion. In the Boreal Mixedwood Ecoregion, forest stands were less diverse with aspen, balsam poplar, and white spruce being the typical species of moderately well drained substrates (Photograph 2). Jack pine stands in the Loon River area occurred infrequently and their occurrence was usually limited to xeric, coarse-textured soils. In contrast, black spruce stands were very common in poorly drained depressions in the Loon River area (Photograph 3), but were less abundant in the other study areas. Old-growth upland stands in all four areas were dominated by white spruce with stem heights ranging up to 28m.

The understory vegetation of the four areas was typified by tall and medium shrubs and a scattered cover of herbs. In the Foothills Ecoregion, alders, low-bush cranberry, and marsh reedgrass were common understory components. Disturbed sites were commonly revegetated by alder and marsh reedgrass as well as introduced species such as awnless brome, timothy, and crested wheatgrass. The understory of upland forest stands in the Loon River area contain low-bush cranberry, prickly rose, and marsh reedgrass. The latter two species, along with aspen and balsam poplar suckers were common on disturbed sites.

Development of oil and gas resources in all three areas appears to have started after the mid-1950's (Anonymous, 1955-1960). However, initial exploration and geophysical activities probably began at least 10 years before development. In the Nordegg River area, geophysical exploration began about 1940 (Smiley, 1973). This implies that some of the seismic lines within the study areas could be at least 20-25 years old, although many have been created within the past 10 years.

METHODS

Photography and Imagery Interpretation

The selection of Landsat imagery began with a review of microfiche files at the Alberta Remote Sensing Center. When reviewing the microfiche, an attempt was made to select "cloud-free" scenes that occurred during late summer and mid-winter in the general area of known oil and gas activity.

Once a selection was made, a sample set of Thematic Mapper and Multisipectral Scanner satellite images were ordered from Energy, Mines and Resources Canada, Canada Centre for Remote Sensing, Prince Albert Satellite Station in Prince Albert, Saskatchewan. Both MSS and TM imagery were available in either paper print or film positive format - 1:1,000,000 (MSS only), 1:500,000, 1:250,000, and 1:125,000 (TM only) scales. These products were available in black and white (single bands), 3-band color infrared, natural color, or custom color composites. For this study, paper prints and film positives were used of TM and MSS imagery, respectively. Black and white images were used throughout, except when three bands were combined (e.g. Bands 2+3+4 or noted as TM234) to produce false color infrared images. Table 1 summarizes the types of imagery and photography used in this study and some of their basic characteristics.

TM and MSS images were visually interpreted for disturbance features using a 2X magnifying handlens. In addition, the satellite imagery was interpreted without reference to any aerial photography to avoid the inclusion of features which might not be readily visible. The contemporary aerial photography was used later to assess the interpreter's ability to detect seismic lines and other linear features on various Landsat images. It is acknowledged that a greater percentage of linear disturbances could probably be extracted from the TM and MSS imagery through computer enhancement of the data. However, such equipment is not available to most potential users, thus a more basic approach was used in this study.

Prior to image interpretation, a sheet of clear polyester film was manually superimposed on each image using registration tabs and pins. This served to protect the image surface from defacing and facilitated precise re-positioning of the overlay. The locations of linear features were then marked directly on the overlay sheet with fine-point marking pens. All imagery and aerial photographs were initially mapped by one interpreter, checked by a second, and later (3-4 days) rechecked by both interpreters. It was found during the final checking, the visibility of disturbance features on paper prints was somewhat enhanced by placing the image on an illuminated light table.

Conventional black and white panchromatic aerial photographs (approximately 1:60,000 scale) of each study area were obtained from Alberta Bureau of Surveying and Mapping, Edmonton. It was important to select photography of similar scales and as contemporary as possible. From these photographs, disturbance features associated with oil and gas development were mapped, transferred to 1:50,000 NTS map sheets, and coded for relative width: small (<10m); medium (10-25m); and large (>25m). The aerial photography served as a control for assessing the relative detail of the Landsat images.

Field Data Collection

It was necessary to collect site-specific data to determine why various features were or were not visible on Landsat imagery. The variables selected for collection were in part limited by project season (late January). The following fifteen variables were collected:

1. Width or shortest axis of disturbance;
2. General height of vegetation (>6m) surrounding the disturbance;
3. Total percent deciduous cover (>6m) in the vegetation surrounding the disturbance;
4. Total percent coniferous cover (>6m) in the vegetation surrounding the disturbance;
5. Total percent deciduous and herbaceous vegetation cover (<6m) in the understory of undisturbed vegetation which surrounded the disturbance feature;
6. Total percent evergreen vegetation (including both coniferous trees and continuously leaved plants such as Labrador tea and bog cranberry) cover (<6m) in the understory of undisturbed vegetation;

7. Average vegetation height on the disturbance;

8. Total percent deciduous and herbaceous vegetation cover on the disturbance;

9. Total percent evergreen cover on the disturbance;

10. Percent unvegetated ground on the disturbance area;

11. Percent slope of the disturbance feature;

12. Approximate amount of relief on the disturbance feature (vertical distance between knolls and depressions in hummocky terrain);

13. General aspect or direction of slope where the disturbance occurred;

14. Orientation (azimuth) of disturbance feature; and

15. Type of disturbance feature (e.g. seismic line, secondary road, pipeline).

Sites for measuring these variables were distributed in proportion to the area associated with each of the three disjunct study areas. Sites selected for measurement were limited to disturbance features that were accessible from roads easily travelled in winter. In addition, only sites with a relatively homogeneous native vegetation cover were selected for measurement. This procedure avoided both measurement and interpretational problems associated with having more than one vegetation type within a set of measurements (e.g. an aspen or a black spruce stand was selected for measurement at a site, but not both). Also, linear features were not measured if they had been created recently (1-2 years), since such recent disturbances would have postdated the imagery.

Analysis of Data

The effectiveness of Landsat imagery to portray linear disturbance features was determined after comparing aerial photo interpretations. The following procedure was used:

- interpreting, locating, and plotting linear features from the aerial photgraphs onto 1:50,000 NTS map overlays;

- interpreting, locating, and plotting linear features from MSS and TM images onto a separate set of map overlays using the first (aerial photo) plot as a guide;

- measurement of total length of linear development as taken from aerial photographs (considered to be interim "ground truth");

- measurement of total length of visible linear development on the Landsat images; and

- calculation of similarity indices.

Two similarity indices were used to evaluate the effectiveness of MSS and TM satellite imagery for detecting linear disturbances compared to conventional photography. The following index was used to estimate the absolute effectiveness:

$$IS_a = (C / A) X 100$$

IS_a - Index of Similarity

C - Length of linear disturbance (km) common to selected imagery and conventional photography

A - Total length of linear disturbance (km) on aerial photography

Table 1. Characteristics of the Thematic Mapper (TM) and Multispectral Scanner (MSS) Imagery, and Aerial Photography

IMAGERY	DATE OF PHOTOGRAPHY (Day.Month.Year)				FORM	SCALE (x1000)	WAVELENGTH OF DETECTION [1] (micrometers)
	Nordegg River	Wapiti	Big Mtn. Creek	Loon River			
TM S234[2]	02.08.85	04.08.84	04.08.84	28.07.84	Color	1:250	0.52-0.90 (Green-Near IR)
TM S3	02.08.85	04.08.84	04.08.84	28.07.84	B/W	1:250	0.63-0.69 (Red)
TM W3	22.01.85	24.11.84	24.11.84	17.11.84	B/W	1:250	0.63-0.69 (Red)
TM S5	02.08.85	-	-	28.07.84	B/W	1:250	1.55-1.75 (Middle IR)
TM W5	22.08.85	24.11.84	24.11.84	-	B/W	1:250	1.55-1.75 (Middle IR)
TM S7	02.08.85	04.08.84	04.08.84	28.07.84	B/W	1:250	2.08-2.35 (Middle IR)
TM W7	22.01.85	24.11.84	24.11.84	-	B/W	1:250	2.08-2.35 (Middle IR)
MSS S2	02.08.85	04.08.84	04.08.84	28.07.84	B/W	1:1,000	0.6-0.7 (Red)
MSS W2	22.01.85	24.11.84	24.11.84	17.11.84	B/W	1:1,000	0.6-0.7 (Red)
MSS S4	-	-	-	02.07.84	B/W	1:1,000	0.8-1.1 (Near IR)
MSS W4	-	-	-	17.11.84	B/W	1:1,000	0.8-1.1 (Near IR)
MSS S124	02.08.85	04.08.84	04.08.84	-	Color	1:1,000	0.5-0.7, 0.8-1.1 (Green-red and Near IR)
MSS W123	-	24.11.84	24.11.84	-	Color	1:1,000	0.5-0.8 (Green-Near IR)
Panchromatic	10.05.84	07.07.83	07.07.83	16.07.84	B/W	1:60	0.5-0.7 approximately

1 Taken from Anonymous (1982) and Strome et al., (1975).
2 An S or W proceding the band number indicates the season of the imagery (i.e. Summer or Winter, respectively).

Table 2. A Comparison of Landsat Imagery for their Effectiveness in Detecting Linear Disturbances

	TM 234	TM S3	TM W3	TM S5	TM W5	TM S7	TM W7	MSS S2	MSS W2	MSS W4	MSS W123	MSS S124
TM 234	....			A comparison of imagery types against total km (8084) of disturbances according to aerial photographic inventory, based on Index of Similarity (IS_a)								
TM S3	21.8	....										
TM W3	19.8	17.7	....									
TM S5	22.8	9.9	16.8	....								
TM W5	19.5	19.4	17.7	18.6	....							
TM S7	25.4	22.8	19.5	26.6	19.4	....						
TM W7	15.8	15.1	15.0	-	14.8	15.0	....					
MSS S2	12.8	12.4	11.4	9.0	17.0	11.7	13.6	....				
MSS W2	12.5	13.6	11.7	7.9	17.6	11.6	14.3	12.3	....			
MSS W4	2.1	2.0	1.9	2.0	-	2.0	-	2.0	2.0	....		
MSS W123	20.0	21.0	19.1	-	10.6	19.0	13.6	18.2	18.5	-	....	
MSS S124	19.2	20.2	17.4	-	18.0	17.8	13.5	18.3	19.3	-	18.6	....
TM 234	....			A comparison of imagery types based on Jaccard Index of Similarity (IS_j), according to detected km of disturbance								
TM S3	51.4	....										
TM W3	45.2	46.1	....									
TM S5	48.4	46.2	37.5	....								
TM W5	46.3	45.8	40.3	40.1	....							
TM S7	52.4	41.8	36.8	54.1	45.8	....						
TM W7	37.3	42.5	44.6	-	32.9	34.5	....					
MSS S2	34.7	41.7	39.0	24.6	38.0	29.1	53.8	....				
MSS W2	34.2	42.3	39.6	21.8	40.0	29.2	58.6	82.0	....			
MSS W4	6.7	8.6	7.4	6.6	6.7	5.6	- -	41.8	51.9	....		
MSS W123	49.0	60.9	55.6	-	38.1	49.5	47.7	71.5	73.8	-	....	
MSS S124	47.7	60.0	50.8	-	43.0	46.6	50.2	-	84.6	-	71.5	....
Disturbance Detected(km)	2891	2291	2253	1769	1109	3073	913	1124	1081	69	714	1010

The calculation of relative similarity among image types was conducted in a similar manner, except the denominator (A) was redefined:

$$IS_j = (C / a + b - C) X 100$$

IS_j - Jaccard Index of Similarity (Mueller-Dombois and Ellenberg, 1974)

a - Total length of linear disturbance (km) detected on first image

b - Total length of linear disturbance (km) detected on second image

C - Length of linear disturbance (km) common to compared imagery types

Both similarity indices produce values that range from 0 to 100 (Table 2). Values close to 100 indicate a high degree of similarity between two compared data sets, while lower values represent reduced degrees of similarity. However, the two indices are not directly comparable. For example, IS_j values represent the average amount of similarity between compared items which excludes features not detected by either imagery. Whereas, IS_a values are directly proportional to the amount of similarity between compared items based on total amount (km) of possible disturbance.

To determine why different linear features were or were not visible on the Landsat imagery, field and associated image data were analyzed with the aid of MIDAS (Michigan Interactive Data Analysis Systems) computer programs, which were available through the University of Alberta (Fox and Gurrie, 1976). Included in these analyses were basic descriptive statistics as well as multivariate techniques (e.g. discriminant analyses). The description of field data primarily relied upon the use of non-parametric statistics, since individual variables were not always normally distributed. However, it was assumed that field data were part of a multivariant normal population (Stopher and Meyburg, 1979).

Due to the highly variable character of most linear disturbance features and their surrounding landscapes, only those segments where field measuring actually occurred were classified as either visible or non-visible, since any particular feature could have both visible and non-visible segments.

RESULTS

Characteristics of Mapped Disturbance Features

Approximately 1500km of linear disturbance occurred in each of the study areas as detected from aerial photography, except Loon River which had 3250km. A total of 8084km of linear development occurred, with narrow lines a clear majority.

Narrow features were dominated primarily by seismic lines and an occasional trail, and comprised 83% of the measured linear disturbances. Medium width features consisting of secondary roads and small pipelines, comprised approximately 15%. Within the large category, power transmission line corridors, pipelines, railroads, and main roads made up 2% of total measured linear disturbance.

In addition to linear features, 436 areal disturbances such as well sites, airstrips (2 only), and gas processing plants (4) were recognized on the aerial photographs. Well sites were the smaller of these areal disturbances and were usually more than 120m in width. These data imply an average of 12 well sites and 230km of linear disturbance occur per 100km^2.

Photographs 4-8 represent examples of TM and MSS imagery taken from a portion of Wapiti map area. Photograph 9 illustrates the relative size, amount, and general position of linear features within the selected area as interpreted from 1:60,000 aerial photographs. Winter and summer TM and MSS scenes have been included for comparative evaluation.

Imagery Detection Effectiveness

The effectiveness of various images for resolving (or detecting) linear features was determined by comparing the length of disturbance per image type with the quantity detected on aerial photographs. The results were as follows:

IMAGERY	SEASON	PERCENT DETECTED
TM7	Summer	38.0
TM 234	Summer	35.8
TM 5	Summer	35.5
TM 3	Summer	28.3
TM 3	Winter	27.9
MSS 123	Winter	23.0
TM 5	Winter	22.9
MSS 124	Summer	20.9
TM 7	Winter	18.9
MSS 2	Summer	13.9
MSS 2	Winter	13.4
MSS 4	Winter	2.1
MSS 4	Summer	0

Summer bands of TM 7, 234, and 5 were best for locating linear disturbances, although none showed 50% (range 29 to 49%) of the available features within any particular study area. In general, more resolvable MSS products (123 and 124) were similar to the least resolvable TM bands (winter 5 and winter 3). Winter MSS or summer TM were better for detecting linear features than summer MSS or winter TM. Both summer and winter imagery of MSS Band 4 were very poor for detecting linear disturbances. A comparison of similar TM and MSS spectral bands (e.g. TM 3 and MSS 2) indicated that 60 to 100% more features were detectable on TM than on MSS imagery.

Table 2 summarizes the comparability of various TM and MSS image for detecting linear disturbances in forested regions. Most TM/TM comparisons resulted in Jaccard Similarity Indices (IS_j) between 32 and 52; whereas MSS/MSS comparisons produced indices between 41 and 85. Generally, the comparison of TM/MSS imagery resulted in indices that ranged from 21 to 61, except the comparison of TM and MSS W4 imagery, which did not exceed an index value of 10. It should be noted that imagery with higher Jaccard Similarity Indices were commonly associated with low levels of absolute detectability. As a result, it appears that MSS image bands are more similar in data content and are of less value for differentiating features than TM imagery.

Photographs 4 - 10

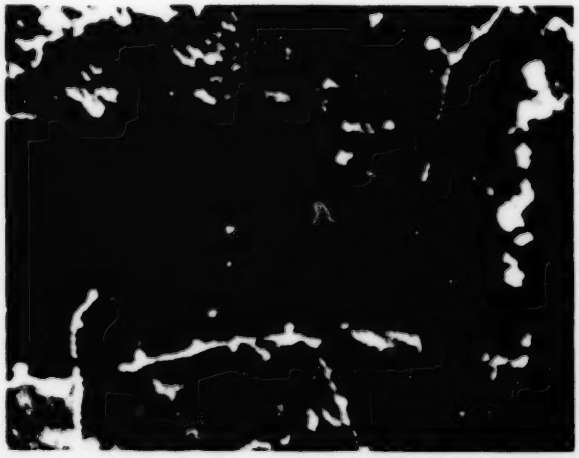
Thematic Mapper and Multispectral Scanner Images (shown here at 1:186,500 scale) from the Wapiti map area are presented to illustrate the detectability of linear features relative to the total amount that occurred within the area (Photograph 9). By comparing these images with Photograph 9, users can judge for themselves the relative visual merits of the various image types. Photograph 10 illustrates seismic lines on supplementary aerial photography.

Photograph 4

An example of TM 234 taken in August 1984: A - gravel surface haul road used for various petroleum exploration and forestry activities, B - secondary service road, C - seismic line traversing an aspen forest, D - seismic line traversing a coniferous forest stand, and E - well site.

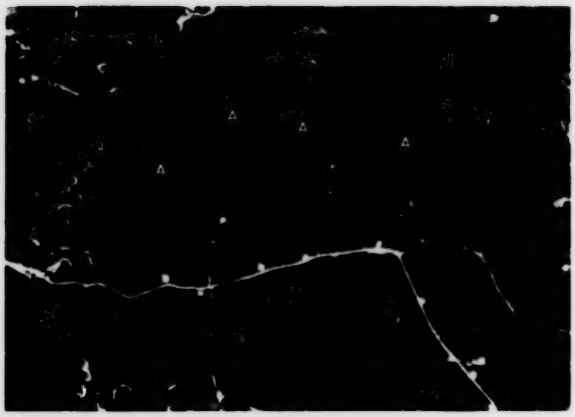
Photograph 5

A summer MSS 124 scene. Usually, seismic lines are not detectable unless good contrast exists between the disturbance feature and the surrounding vegetation (A).



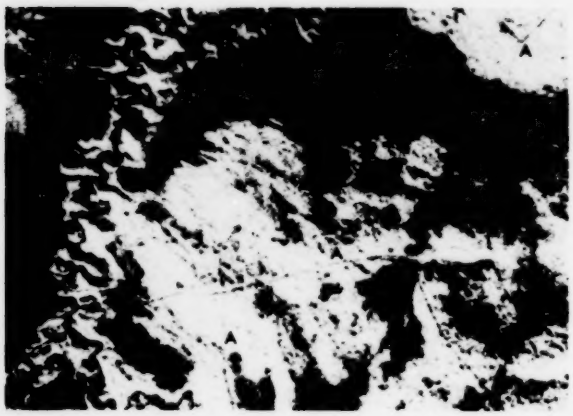
Photograph 6

MSS 123 winter imagery. The general visibility of both wide and narrow features is better on MSS 123 than MSS 124 (summer) imagery, but neither have the clarity of TM 234 or TM 7.



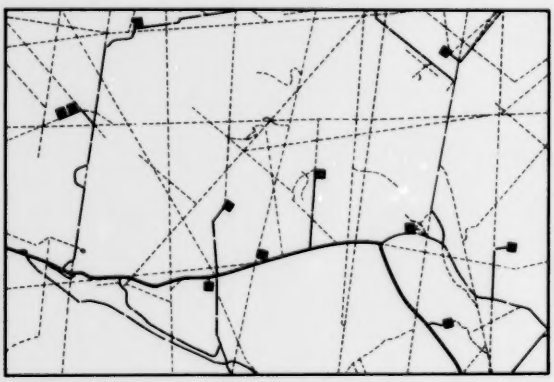
Photograph 7

An example of TM 7 summer imagery. The clarity of this image is equalled only by the TM 234 image. Seismic (narrow) lines are relatively abundant on this image (A).



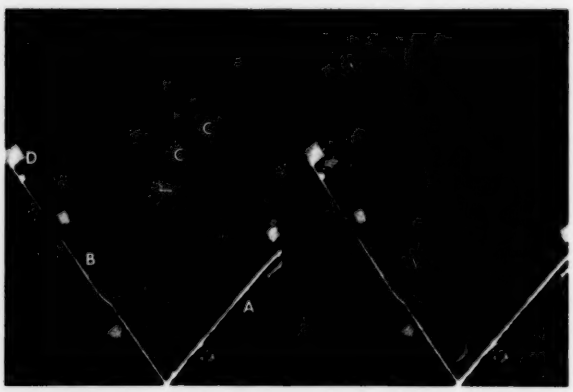
Photograph 8

TM 7 winter imagery. Only wide features (large lines) such as roads are readily visible (A).



Photograph 9

The location and relative size of linear disturbances in a selected portion of the Wapiti map area are portrayed in this diagram. This area is equivalent in location and scale to the images shown in Photographs 4-8. Linear disturbances >25m in width are represented by the larger solid lines, 10-25m are represented by a long dashed line, and <10m wide lines are represented by short dashed lines; while the solid boxes indicate the location of well sites. By comparing this diagram with Photographs 4-8, users can assess the relative merits of TM and MSS imagery for detecting linear disturbances.



Photograph 10

An aerial photograph stereogram (Gov't. of Alberta AS 2785 290-291, 1:60,000) with examples of a haul road - "large lines" (A), secondary service road - "medium lines" (B), seismic lines - "narrow lines" (C), and a well site (D).

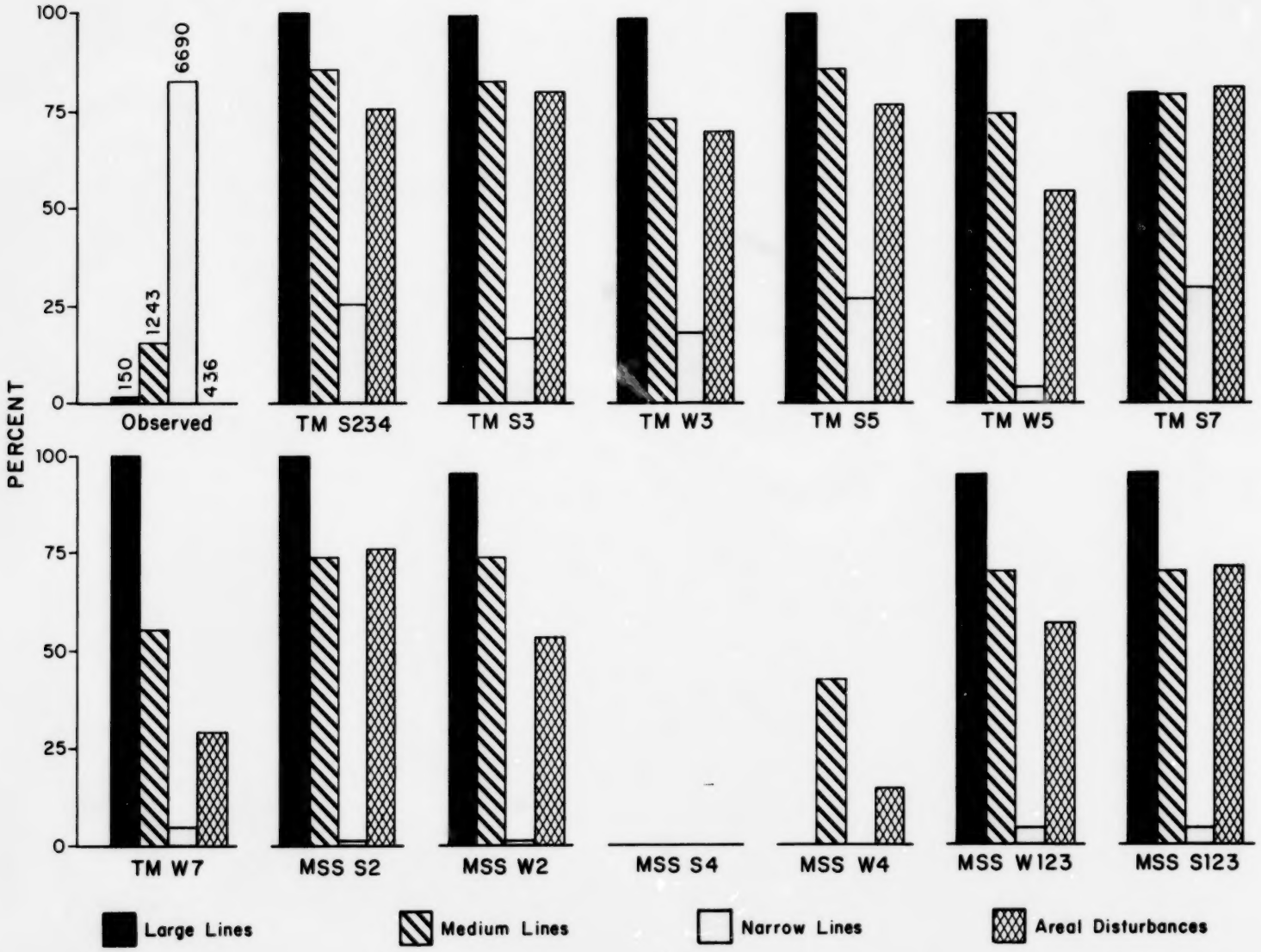


Figure 2. The proportion of lines detected on selected LANDSAT imagery relative to that detected on 1:60,000 aerial photography (Observed category). The numbers associated with the Observed category represent the total km of disturbance in each grouping, whereas the value given for Areal Disturbances (right-hand number, 436) represents the total number of observed areal disturbances.

The comparison of TM and MSS imagery on an absolute basis in accordance with the total amount of disturbance in the study areas resulted in Indices of Similarity (IS_a) which were low compared to those of "within image type" comparison (e.g. TM/TM). Comparisons of TM and MSS imagery produced Similarity values that ranged from approximately 2 to 21, with winter MSS 4 imagery consistently occurring at the lower extreme of this range (Table 2). In general TM/TM comparisons tend to cover the entire index range, while MSS/MSS comparisons tended to occupy the middle portion of the range.

Figure 2 summarizes the detectability of disturbance features on the basis of width. All imagery showed >95% of the available linear features with widths >25m, except TM S7 (approximately 70%). No large lines occurred in areas where MSS 4 imagery was provided, thus this particular width class could not be tested. In total, large linear features comprised only 1.9% of the available lines. Approximately 55% to 85% of all medium width features (10-25m) were detected. TM W7 was the least effective imagery for detecting linear disturbance features, while TM S234, TM S7, and TM S5 were the most effective. Most imagery showed more than half of all areal disturbances, which were usually >120m in width, except TM W7 and MSS 4.

TM S234 and TM S5 appear to be equally suitable for the detection of disturbance features, but somewhat better than TM S7 on an overall basis, although the latter was found to have the greatest total effectiveness (See Imagery Detection Effectiveness). Their slight advantage stems from the fact that TM S7 was not as effective at showing wide disturbances (Figure 2). However, it was more effective at detecting narrow features (<10m wide).

Characteristics of Field Data

A total of 200 sets of field measurements, (15 variables each) were collected from the four study areas. Included within the data set were 136 seismic lines and trails, 38 roads, and 26 other disturbance features such as pipelines, railroads, and power corridors. These disturbance features ranged from 3 to 140m in width.

Approximately 63% of the field sites were composed of deciduous stands, while conifer dominated stands represented 21%. Mixed aspen, balsam poplar, and white spruce stands made up the remaining field sites. Black spruce, white spruce, and lodgepole pine stands were equally represented in the coniferous subset. Jack pine comprised three sites. The understory vegetation of forest stands was typically dominated by deciduous and herbaceous plants, with small percentages of evergreen cover.

During the early stage of revegetation, most disturbed sites were dominated by grass and weed species which were introduced as a result of site reclamation activities and natural succession processes. However, shrubs and tree saplings increased in cover and height as the disturbances aged, if left undisturbed. Evergreen species were uncommon on disturbed areas, except in black spruce stands and on older disturbances. The amount of unvegetated ground associated with disturbance features ranged up to 100%, but was usually less than 10%.

Most field measuring occurred on level to very gently sloping terrain with an even surface. The orientation of disturbance features was highly varied, though approximately 25% of the 200 measured sites were north-south trending.

Photographs 11-14 represent selected examples of linear features which were observed during field work. These examples are typical of many disturbance features in the four study areas, but do not represent the total possible variations in vegetation, degrees of regrowth, or widths of disturbance.

Field Data Analysis

In an attempt to determine what landscape characteristics promoted or hindered the detectability of linear features on the images, the field data were subdivided into visible and non-visible categories according to the image analysis results. Each data subset was subsequently analyzed by Discriminant Analysis (Table 3) using linear distance criteria which is a common technique (Breiman et al., 1984).

Discriminant Analysis is a statistical technique for evaluating the variance within two sets of data composed of several variables. The purpose of such an analysis was to determine which variables could be used to separate (or account for the difference between) the data sets. **Which variables were causing the visibility or invisibility of disturbance features on the images?** The identification of important variables was based on F-ratios. Stepwise Discriminant Analysis uses similar criteria for data analysis, except that variables were systematically excluded from the data set. Variables were excluded from the analysis in order of their relative importance (e.g. most to least important) according to the F-ratio.

Of the 14 tested variables, only four were consistently important as criteria for separating visible and non-visible linear features: width of disturbance; percent deciduous cover; percent unvegetated ground; and relief of disturbance feature. Width was the most important factor, except in the case of winter TM 3 and 5 imagery where the percentage of unvegetated ground was most important (Table 3). Features detected on TM images were usually greater than 7m in width, while MSS required minimum widths of 20m. Widths associated with winter TM imagery tended to be greater than those on summer images. Stepwise Discriminant Analyses indicated that unvegetated ground was usually the second most important characteristic for separating visible and non-visible features. For example, visible features were commonly associated with the occurrence of unvegetated ground, while non-visible features were almost exclusively associated with the lack of unvegetated ground. Percent deciduous cover on disturbed sites was also statistically significant, but represents the inverse character of unvegetated ground, thus was not an independent variable. Local relief was statistically significant, but of lesser importance than width or unvegetated ground. As a general rule, visible features were associated with greater degrees of local relief or topographic variability (e.g. hilly terrain).

Table 3. Summary of Discriminant Analysis Results Based on F-Ratios

VARIABLES	TM S234	TM S3	TM W3	TM S5	TM W5	TM S7	TM W7
Undisturbed Features							
Overstory							
Height	0.0	0.1	9.5*	7.1*	0.1	0.3	0.3
Deciduous cover	0.2	0.4	1.7	0.3	0.2	0.9	0.3
Coniferous Cover	2.0	1.1	0.0	7.3+	0.2	2.1	0.1
Understory							
Deciduous Cover	0.1	0.1	0.0	0.0	0.5	2.1	0.9
Evergreen Cover	1.3	0.2	2.6	0.2	0.2	1.9	0.1
Aspect	0.3	0.0	5.5+	1.0	0.4	0.0	1.4
Disturbed Features							
Width	55.2▲	91.8▲	26.6▲	22.1▲	29.5▲	74.1▲	28.2▲
Vegetation Height	1.6	3.9+	7.5*	0.0	1.7	6.0*	0.8
Deciduous Cover	14.0▲	30.7▲	28.1▲	2.6	44.8▲	20.6▲	31.9▲
Evergreen Cover	0.1	0.2	0.1	0.0	0.4	0.9	0.2
Unvegetated Ground	17.1▲	36.7▲	32.1▲	3.2	46.5▲	32.3▲	34.1▲
Orientation	0.0	1.7	8.8*	0.1	0.5	0.1	2.9
Slope	1.8	4.2+	0.0	2.0	0.1	2.1	0.2
Relief	17.8▲	16.4▲	8.4*	4.0+	18.6▲	18.3▲	11.6▲
Number of Cases	200	200	200	100	150	200	150

	MSS S2	MSS W2	MSS S4	MSS W4	MSS W123	MSS S124
Undisturbed Features						
Overstory						
Height	0.1	0.2	0.0	0.5	5.9+	0.8
Deciduous Cover	0.0	0.2	0.0	1.7	0.0	0.1
Coniferous Cover	0.8	0.1	0.3	0.7	0.1	0.5
Understory						
Deciduous Cover	0.6	0.1	0.0	0.2	1.6	0.0
Evergreen Cover	1.2	0.1	0.0	0.0	0.7	0.0
Aspect	0.3	0.7	0.0	1.2	0.7	0.6
Disturbed Features						
Width	183.0▲	199.9▲	0.0	73.7▲	94.5▲	139.6▲
Vegetation Height	2.5	1.7	0.0	3.2	3.3	3.4
Deciduous Cover	43.6▲	40.7▲	0.0	9.6*	44.3▲	63.0▲
Evergreen Cover	0.3	0.2	0.0	0.2	1.7	0.0
Unvegetated Ground	75.0▲	61.4▲	0.0	14.1▲	45.4▲	96.2▲
Orientation	0.5	1.9	0.0	0.4	1.7	5.7+
Slope	5.0+	3.3	0.0	0.0	0.3	5.3+
Relief	41.8▲	45.7▲	0.0	1.0	38.2▲	72.3▲
Number of Cases	200	200	50	50	100	150

Probability Levels ▲ = $P < 0.001$ * = $P < 0.01$ + = $P < 0.05$

Underscored values indicate two most important variables according to Stepwise Analysis

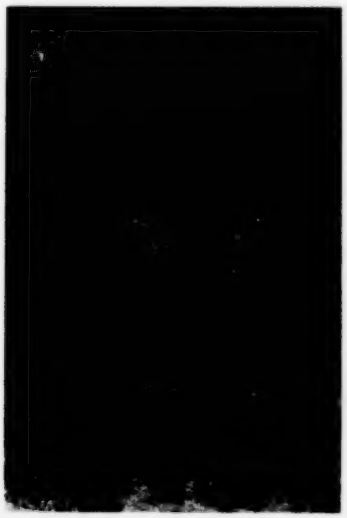
Photograph 11

A secondary road which was visible on most TM and MSS imagery. This disturbance was approximately 18m in width, with a high percentage of unvegetated ground.

Photograph 12

A powerline (19m wide) with moderate regrowth. This feature was visible only on TM imagery, due to its small percentage of unvegetated ground (<5%).

Photograph 13 a



Photograph 13 b

Two linear disturbance features that were not detected by either TM or MSS imagery. Both lines were narrow (<7m) and had a 100% vegetation cover.

Further analyses of the data suggested that certain combinations of characteristics may either enhance or detract from the detectability of a linear feature on an image. For example, the visibility of a disturbance with a high percentage of deciduous regeneration is enhanced when conifers occur in the surrounding undisturbed vegetation. Conversely, deciduous forest stands could reduce the visibility of disturbance features with extensive deciduous regeneration. To attain visibility in deciduous vegetation, a disturbance would have to be revegetated solely by coniferous vegetation. This is not a common ecological condition in Alberta.

The height of plants on disturbed sites relative to the surrounding vegetation would seem to be an important factor in determining the visibility of disturbance features, particularly older sites with extensive regrowth. However, it was not possible to clearly differentiate height ranges for visible and non-visible disturbances. It will be necessary to collect and analyse additional data from disturbances with extensive regrowth to either prove or disprove this hypothesis. Furthermore, it was concluded that orientation does not appear to be an important factor in either promoting or hindering detectability.

CONCLUSIONS AND DISCUSSION

It is apparent from the preceding results that TM imagery is better suited than MSS for detecting linear disturbances. This capability stems from its increased spatial (and/or spectral) resolution and corresponding larger scale. Although not perfect*, conventional aerial photography remains superior, since <40% of all linear features were visible on the TM imagery. Linear features >10m in width, such as secondary roads, highways, and major utility lines had a detection rate of >75%, while features <10m were visible <30% of the time. Summer TM 7, 234, and 5 were the most effective imagery for detecting linear features of the types tested. Of these types, the latter two were considered to be more useful than TM S7, which was somewhat more effective for detecting narrow (<10m wide) features.

It was not possible to assess whether or not color composite images, other than those tested, would prove more effective for detecting linear features. The synchronous use of two separate images might increase the overall effectiveness of TM imagery, since no two images had more than approximately 55% detection similarity. For example, if TM S7 and TM S234 were used together, the cumulative detection effectiveness could theoretically be increased from 35 & 38 to 48%. If another composite image was suggested for testing, TM S245 or TM S345 would be a good possibility, since they both have reflective and absorptive properties for differentiating forest cover types (Benson and DeGloria, 1985).

Since TM S234 and TM S5 are essentially comparable in terms of effectiveness, TM S5 (black and white paper prints) offers the advantage of costing half ($95/image) as much as color TM S235 imagery ($190/image) based on a 1985 Canada Centre for Remote Sensing price list. On the other hand, well sites and other features were more easily detected on TM S234 than on TM S5 imagery because of their bluish coloration. In addition, TM S234 images were found to be easier to interpret due to their diversity of colors. Black and white images are more easily transferred to base maps due to the high contrast between disturbance features and the surrounding landscape (Photographs 7 and 9). Archived panchromatic 1:60,000 photographs from Alberta Bureau of Surveying and Mapping, cost approximately $54/1:50,000 map sheet, and the cost of obtaining new photography would be many times greater. The interpretation of a single TM image and associated tasks required approximately 4 man/hours. Approximately 16 man/hours were required to conduct the same work with aerial photography due to the increased detail available for mapping. It should be noted that larger scale photography would require additional photographs and somewhat more time to interpret, thus increasing costs.

At present, conventional aerial photography offers the only comprehensive remote sensing system for inventorying a wide variety of linear features, although TM can be used for mapping large features with a high degree of efficiency. For monitoring oil and gas development on a periodic basis, TM may be the most economically viable approach.

It was found that 1:250,000 TM images were sufficient for delineating features in areas where development was not extensive, but in more intensly developed areas such as Loon River, a larger scale (e.g. 1:125,000) would have been more appropriate. This change in scale would not increase the data content, but it would increase the ease of mapping. TM imagery appears to be best suited to mapping scales of 1:50,000 or less; similar conclusions have been reached by others (e.g. Benson and DeGloria, 1985; Welch and Usery, 1984).

The reasons why linear disturbances are visible on satellite imagery appear to be quite varied. Theoretically, many of the linear features detected on imagery should not have been visible, since most were narrower than the 30m spatial resolution of the TM sensor. Disturbances less than 25m in width were usually not detectable on TM imagery, unless a high spectral contrast existed between the disturbance and the surrounding landscape. For example, the presence of unvegetated ground and the occurrence of conifers in the vegetation surrounding the disturbance tended to promote their detection. TM imagery would probably be most successfully applied in areas where mixed deciduous-coniferous and coniferous vegetation predominates. Most revegetation in Alberta is by deciduous and herbaceous species. It may also be useful for detecting seismic lines immediately (probably less than 3 years) after their establishment because plant colonization would be incomplete and the proportion of unvegetated ground would be high; thus a potentially important tool for monitoring recent oil and gas exploration activities.

* Several older and overgrown linear disturbances were noted during field work that were not detected on the aerial photographs. These features' vegetation covers were usually of similar height and character as the surrounding vegetation, or were very narrow (e.g. 2m in width, legal survey lines). The additions would have increased the total amount of detected features by only a small percent (maybe 2-3%).

It is thougnt that the image detection of linear features over the winter months may be severely limited by loss of deciduous foliage. When the leaves are absent the contrast between disturbances and the surrounding vegetation is reduced, and the forest canopy becomes semi-transparent when viewed from above. These characterisitics are common to aerial photography taken during late fall. As a result the disturbance may blend into the surrounding vegetation. Under such circumstances, unvegetated ground may be important for detecting disturbances after snowfall, since it would have a relatively smooth texture as opposed to the blurry texture of the forest vegetation. Disturbances with 1-3m of revegetated woody growth could easily merge with the surrounding vegetation and be undetected, unless the surrounding vegetation was coniferous. Furthermore, it is theorized that snow on the disturbance may enhance contrast when the surrounding vegetation contains a high percentage of conifers. The orientation of a disturbance may influence its detectability as proposed by Wallace and Peaker (1974), but our data does not support this hypothesis.

In summary, the following conclusions can be made with respect to Thematic Mapper imagery as a tool for detecting and mapping linear features:

1. TM imagery was better for detecting linear features than MSS imagery, but less suitable than conventional aerial photography;

2. MSS imagery has a greater degree of internal similarity than does TM, which suggests that the TM has a greater discriminative capability than the MSS. Thus the selection of an optimum TM band is more crucial than with MSS images;

3. Summer TM imagery was much better than winter imagery, whereas winter MSS imagery was better than summer;

4. Threshold width values for detection were larger for winter and MSS imagery than summer and TM imagery;

5. TM S234, TM S5, and TM S7 were the most effective Landsat image products tested;

6. TM S7 was best for detecting narrow features (<10m in width), notwithstanding the less than 30% success rate;

7. Detection effectiveness was greater than 75% for features >10m in width, but less than 30% for those <10m in width;

8. Detection of linear disturbances was primarily controlled by the width of the feature and secondly by factors (e.g. vegetation cover and unvegetated ground) which created spectral contrast between the disturbance and the surrounding landscape;

9. Unvegetated ground and the presence of conifers in the vegetation surrounding the disturbance were important factors that promoted detection;

10. TM imagery may be most successfully applied in areas of extensive coniferous vegetation and least effective in deciduous regions;

11. Orientation neither promoted nor inhibited detection; and

12. TM imagery may be a useful tool for monitoring oil and gas exploration activities, particularly recently created features.

REFERENCES

Ackleson, S.G., V. Klemas, H.L. McKim, and C.H. Merry, 1985. A comparison of SPOT simulator data with LANDSAT MSS imagery for delineating water masses in Delaware Bay, Broadkill River, and adjacent wetlands. Photogrammetric Engineering and Remote Sensing, 51:1123-1129.

Anonymous, 1955-1960. Western Canada wildcats and stepouts. Oil Week, Vol. 6-11.

Anonymous, 1982. Landsat data user notes. U.S. Geological Survey and National Aeronautics and Space Administration, EROS Center, Sioux Falls, South Dakota. Issue No. 23.

Benson, A.S. and S.D. DeGloria, 1985. Interpretation of Landsat-4 Thematic Mapper and Multispectral Scanner data for forest surveys. Photogrammetric Engineering and Remote Sensing, 51:1281-1289.

Brieman, L., J.H. Friedman, R.A. Olshen, and C.J. Stone, 1984. Classification and regression trees. Wadsworth International Group, Belmont, California.

Colwell, R.N. and C.E. Poulton, 1985. SPOT simulation imagery for urban monitoring: A comparison with Landsat TM and MSS imagery and with high altitude color infrared photography. Photogrammetric Engineering and Remote Sensing, 51:1093-1101.

Dutchak, K., 1980. Ecological land classification and evaluation: Brazeau-Pembina. Alberta Energy and Natural Resources, Edmonton, Alberta. ENR Report No. T/11 No.2.

Fox, D.J. and K.E. Guire, 1976. Documentation for MIDAS. Third edition, University of Michigan, Statistical Research Laboratory, Ann Arbor, Michigan.

Hardy Associates (1978) Ltd., 1981. Forest depletion by energy development in the Green Zone of Alberta. Prepared for Alberta Energy and Natural Resources, Edmonton, Alberta.

Horejsi, B.L., 1979. Seismic operations and their impact on large mammals: Results of a monitoring program. Prepared for Mobil Oil Canada Ltd. by Western Wildlife Environments, Calgary, Alberta.

Moss, E.H., 1983. Flora of Alberta, 2nd Edition, revised by J.G. Packer. University of Toronto Press, Toronto, Ontario.

Mueller-Dombois, D. and H. Ellenberg, 1974. Aims and methods of vegetation ecology. John Wiley & Sons, New York, New York.

Pettapiece, W.W., 1985. Physiographic subdivisions of Alberta. Alberta Soil Survey, Alberta Institute of Pedology, Edmonton, Alberta (unpublished).

Smiley, B., 1973. The lower Brazeau drainage district; In J.J. Nowicki; Lower Brazeau Drainage District, Phase I, Alberta Forest Service, Forest Land Use Branch, Edmonton, Alberta.

Snowsill, D.M., 1985. Ordinance survey experience with photography from space. Photogrammetric Record, 11:691-694.

Stopher, P.R. and A.H. Meyburg, 1979. Survey, sampling, and multivariate analysis for social scientists and engineers. Lexington Books, D.C. Heath and Company, Lexington, Mass., pp. 263-285.

Strome, W.M., S.S. Vishnubhatla, and F.E. Guertin, 1975. Format specifications for Canadian Landsat MSS system corrected computer compatible tape. Department of Energy, Mines, and Resources, Canada Centre for Remote Sensing, Ottawa, Research Report 75-3.

Strong, W. L, 1986. Remote sensing of seismic lines - a comparison of Landsat Thematic Mapper and Multispectral Scanner imagery. Prepared for Alberta Remote Sensing Center by Ecological Land Surveys Ltd., Edmonton, Alberta.

Strong, W.L and K.R. Leggat, 1981. Ecoregions of Alberta. Alberta Energy and Natural Resources, Edmonton, Alberta. Technical Report No. T/4.

Tilton, E.L., III and P.K. Conner, 1985. Information extraction from Thematic Mapper data. Acta Astronautics, 12:187-194.

Twardy, A.G. and I.G.W. Corns, 1980. Soil survey and interpretations of the Wapiti map area. Alberta Research Council, Alberta Institute of Pedology, Edmonton, Alberta. Bulletin No. 39.

Wallace, W.L. and J.P. Peaker, 1974. Seismic lines on ERTS-1 images. Canadian Surveyor 28:177.

Welch, R. and E.L. Usery, 1984. Cartographic accuracy of Landsat-4 MSS and TM image data. IEEE Transactions on Geoscience and Remote Sensing, GE-22:281-288.